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RESEARCH MEMORANDUM

AN ANALYTICAL STUDY OF THE EFFECTS OF INCREASING FIN CHORD ON THE LIFT AND LONGITUDINAL STABILITY CHARACTERISTICS OF CONSTANT-SPAN FIN-BODY COMBINATIONS OF FINENESS RATIO 14

By Roland D. English

Langley Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

January 17, 1957

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RESEARCH MEMORANDUM

AN ANALYTICAL STUDY OF THE EFFECTS OF INCREASING FIN CHORD ON THE LIFT AND LONGITUDINAL STABILITY CHARACTERISTICS OF CONSTANT-SPAN FIN-BODY COMBINATIONS OF FINENESS RATIO 14

By Roland D. English

SUMMARY

A limited analysis has been made to determine the effect of increasing the fin-chord length while holding the span constant on the lift and longitudinal static stability of fin-body combinations. Rectangular and triangular fins with spans of 2 and 3 body diameters in combination with a fineness-ratio-14 ogive-cylinder body were studied. Results indicate that, as the chord length is increased, a value is reached where further increases in chord length result in a loss in stability. Lift continues to increase beyond this value, however, and in some cases increases with increase in chord length up to the maximum investigated (11 body diameters). The chord length at which maximum stability occurs is higher at supersonic speeds than at subsonic speeds and is, in general, higher for a triangular fin than for a rectangular fin. No appreciable difference in the chord length for maximum stability was found for ratios of body diameter to fin span of 0.33 and 0.50.

INTRODUCTION

Space limitations and ease of handling necessitate that the fin span of many fin-body combinations (fin-stabilized ammunition, air-to-air missiles, sounding rockets) be kept small. Also, at high Mach numbers the lift-curve slope becomes small even for moderate-aspect-ratio fins. One method of obtaining the fairly large fin area required for stability at these Mach numbers is to increase the chord length. Increasing chord length without a corresponding increase in span decreases aspect ratio, however, and lift-curve slope decreases with decreasing aspect ratio for all plan forms at subsonic speeds and for some plan forms, to a lesser

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degree at supersonic speeds. Also, increasing the chord length toward the nose moves the fin center of pressure forward. It is probable therefore that a chord length is reached at which additional increases result in little gain in lift or stability. The purpose of this paper is to use available methods to study analytically the effect of extending fin chord forward from the body base for rectangular and triangular wings in combination with a fineness-ratio-14 ogive cylinder body at both subsonic and supersonic speeds. Where possible, the calculations are compared with experimental data.

SYMBOLS

A body cross-sectional area

b total fin span

c fin chord

c_f fin chord at fin-body juncture

d body diameter

L lift

l body length

M Mach number

m pitching moment

q dynamic pressure

C_L lift coefficient, L/qA

C_m pitching-moment coefficient, m/qAd

C_{L_α} lift-curve slope, $dC_L/d\alpha$

C_{m_α} slope of pitching-moment curve, $dC_m/d\alpha$

α angle of attack

x_{cp} center of pressure

Subscripts:

0 with reference to body nose

0.5l with reference to body midpoint

CONFIGURATION STUDIED

The body of the configurations selected for study in this paper is one which is typical of fin-stabilized missiles and one for which a wide range of experimental data were available for comparison. The body consists of an ogival nose with a fineness ratio of 2.5 and a cylindrical afterbody with a fineness ratio of 11.5. Rectangular and triangular fins with ratios of body diameter to fin span of 0.33 and 0.50 were studied. Sketches of the configurations investigated are shown in figure 1.

METHOD

Lift-curve slope C_{L_α}, moment-curve slope with respect to the nose $C_{m_{\alpha,0}}$, moment-curve slope with respect to the body midpoint $C_{m_{\alpha,0.5l}}$, and center-of-pressure location x_{cp}, were calculated for root-chord lengths varying from 0 to 11 body diameters. In all cases the lift coefficient was based on body cross-sectional area and the moment coefficient was based on body cross-sectional area and body diameter. The positive directions of forces and moments are given in the sketch in figure 2. Mach numbers selected for the calculations were 0.26, 0.50, 0.80, 1.87, 2.87, and 4.24 and were chosen for the most part for availability of experimental data.

For the rectangular fin at supersonic speeds calculations were made by method A of reference 1, a linearized theory approximation which assumes that neglecting the tip loss in fin lift will exactly compensate for neglecting the interference lift on the body due to the presence of the fins. Values of C_{L_α} were obtained for the triangular fin at supersonic speeds from reference 2 which used exact linearized theory but replaced the body with a flat plate in the plane of the fin. Slender-body theory of reference 3 was used for the center-of-pressure location. For the rectangular fin at subsonic speeds, C_{L_α} was calculated by using a formula obtained by the lifting-line method, an elliptical lift distribution (ref. 4) being assumed. These values were corrected for the presence of the body by the slender-body theory of reference 3 and the center-of-pressure location was assumed to be at the quarter-chord line. The linear low-aspect-ratio theory of reference 5 was used to calculate both

lift and pitching moment for the triangular fin at subsonic speeds. Compressibility effects at subsonic speeds were taken into account on both plan forms by making the Prandtl-Glauert correction. The lift and center of pressure of the body alone (the body not in the presence of the fins) were obtained at both subsonic and supersonic speeds by using slender-body theory (ref. 3). The experimental data were taken from references 6 to 10.

It should be noted that sample calculations were made by several other methods (refs. 11 and 12 in combination with refs. 3 and 13), but the methods described previously were found to give the best agreement with experiment over the entire range of chord lengths investigated.

RESULTS

The variation of C_{L_α}, $C_{m_{\alpha,0}}$, $C_{m_{\alpha,0.5l}}$, and center-of-pressure location with chord length (rectangular fin) or root-chord length (triangular fin) is presented in figures 3 and 4. Included in the figures are experimental data from references 6 to 10. The agreement between experiment and calculations for the rectangular fin is, in general, good. Some discrepancy between experiment and calculation appears in the magnitude of the center-of-pressure location at medium chord lengths (2 to 4 diameters). The trend in the variation of center-of-pressure location with Mach number is, however, in good agreement even at these chord lengths. No experimental data were available for triangular-fin configurations of the type investigated herein. (Experimental verification of the methods used is given in the references from which they were taken.)

It may be noted from the curves of figures 3 and 4 that, as the chord length is increased, an optimum value is reached beyond which an increase in chord length results in a decrease in stability. There are two reasons for the decrease in stability. One is that, as the fin chord is extended forward, the center of pressure of the fins moves forward also. The second is that, as the chord length is increased, the fin aspect ratio and, consequently, the lift-curve slope (based on fin area) is decreased. A chord length is reached at which the increase in fin area is almost entirely offset by the decrease in lift-curve slope. It should be noted, however, that this chord length is considerably higher than the optimum for stability. In other words, the fin lift continues to increase after the stability begins to decrease and, in some cases, the lift continues to increase up to the maximum chord length investigated.

An indication of the effect of changing the ratio of the body diameter to the fin span may be obtained by comparing figures 3(a) and 3(b)

and figures 4(a) and 4(b). For both rectangular and triangular plan forms, the magnitude of C_{L_α} and C_{m_α} is greatly reduced by increasing d/b from 0.33 to 0.50. No appreciable change, however, occurs in the chord length for maximum stability when d/b is increased. Also, C_{L_α} continues to increase with an increase in chord length up to the maximum investigated for both ratios of body diameter to fin span.

The data for $C_{m_{\alpha,0.5l}}$ of figures 3 and 4 are cross plotted in figure 5 as the variation of chord length for maximum stability with Mach number. The chord length for maximum stability remains fairly constant at subsonic speeds. At supersonic speeds, the chord length for maximum stability is higher than at subsonic speeds and increases with increase in Mach number. In general, chord length for maximum stability is higher for the triangular fin than for the rectangular fin.

CONCLUDING REMARKS

An analytical study of the effect of increasing the fin-chord length while holding the span constant on the lift and longitudinal stability of the fin-body combinations indicates that, as the chord length is increased, a value is reached at which further increase in chord length results in a loss in stability. The lift, however, continues to increase as the chord length is increased beyond this value and, in some cases, increases up to the maximum chord length investigated (11 body diameters). Changing the ratio of the body diameter to fin span from 0.33 to 0.50 reduced the magnitude of lift and moment-curve slope but did not appreciably change the chord length for maximum stability. The chord length for maximum stability is higher at supersonic speeds than at subsonic speeds and increases with increasing supersonic Mach number. The chord length for maximum stability is, in general, higher for a triangular fin than for a rectangular fin by about 1/2 to 1 body diameter, depending on Mach number.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 26, 1956.

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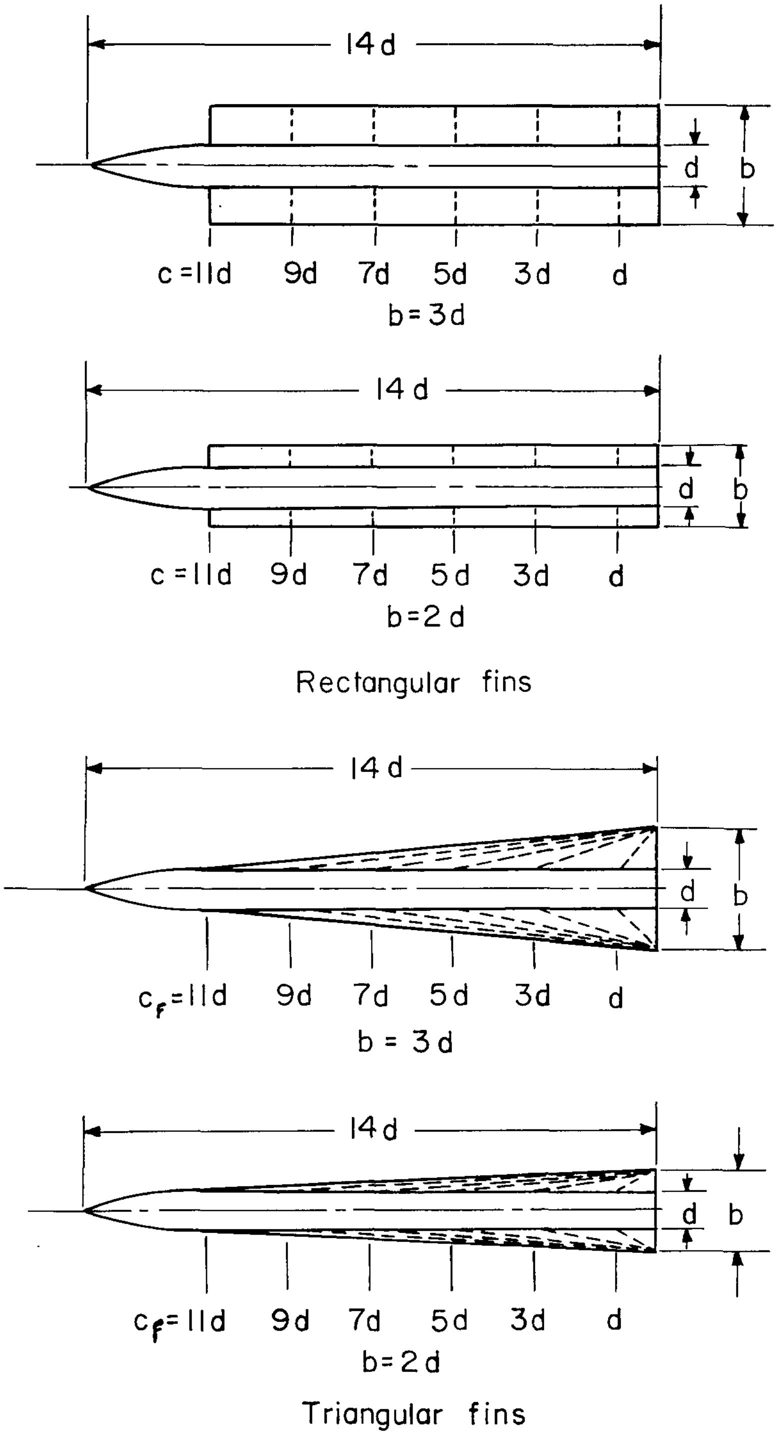

Figure 1.- Sketches of configurations studied.

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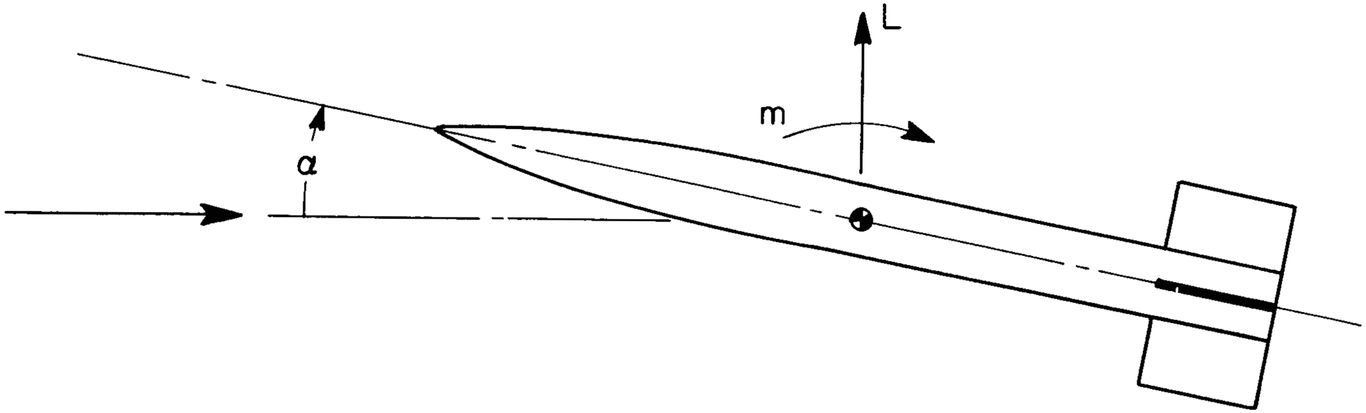

Figure 2.- Sketch showing positive direction of forces and moments.

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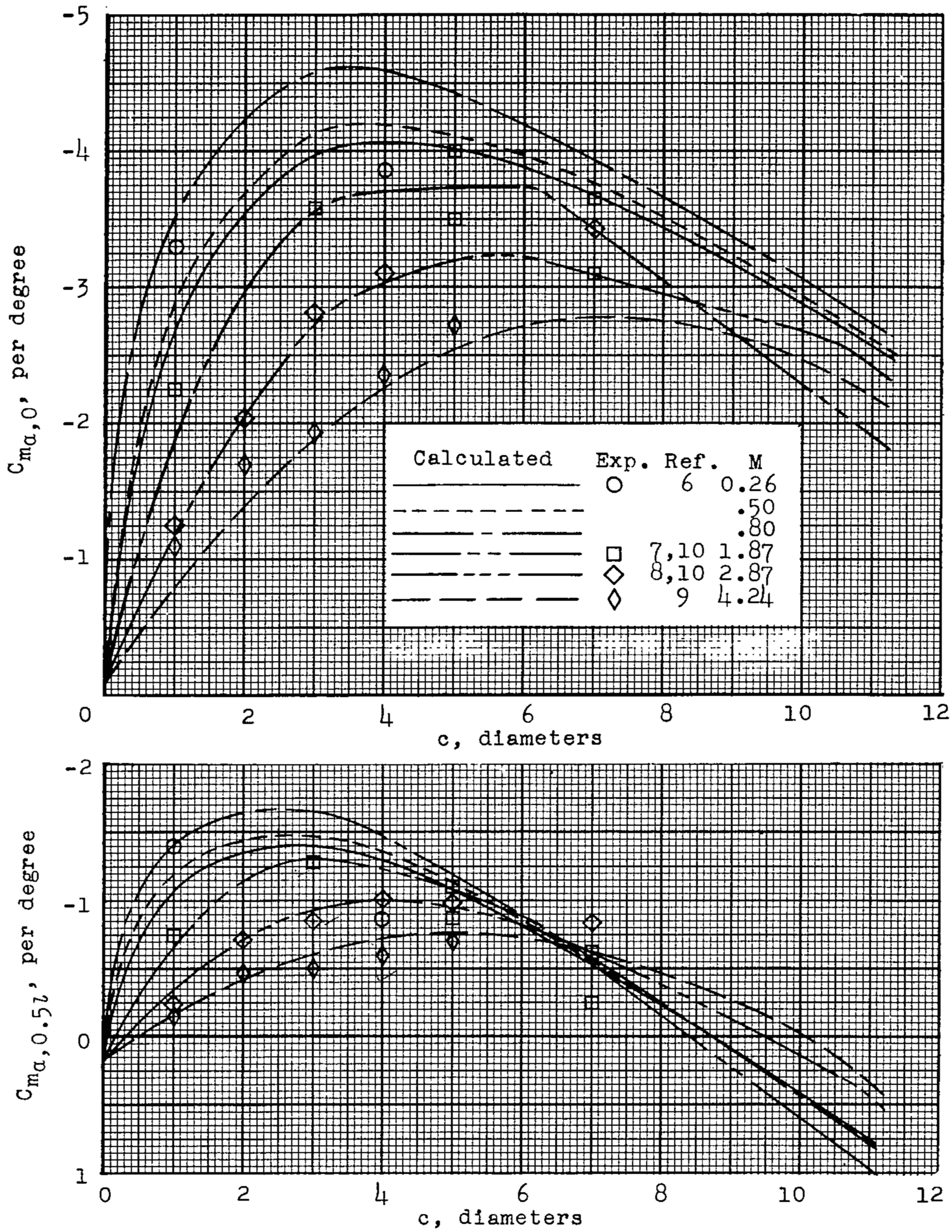
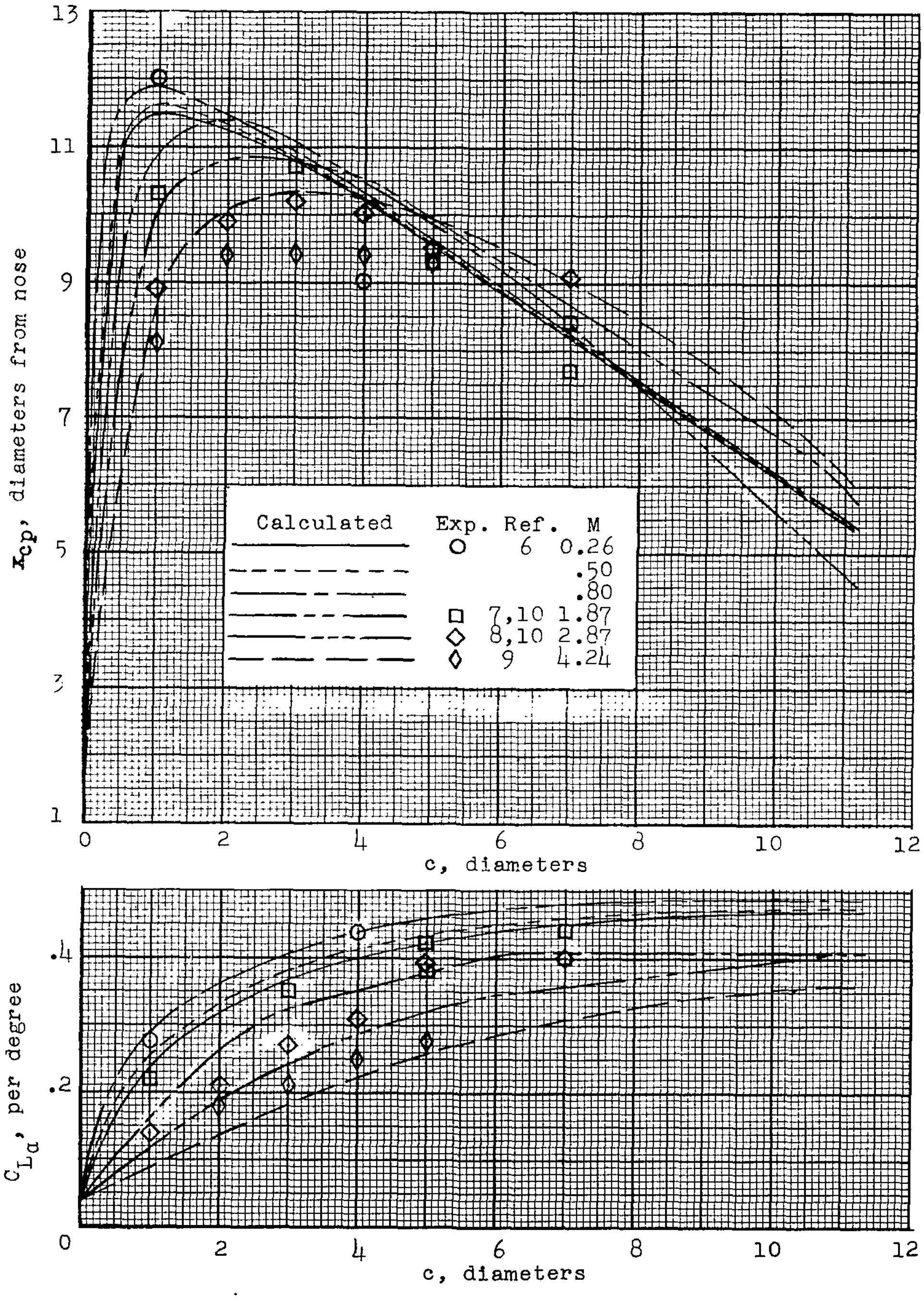


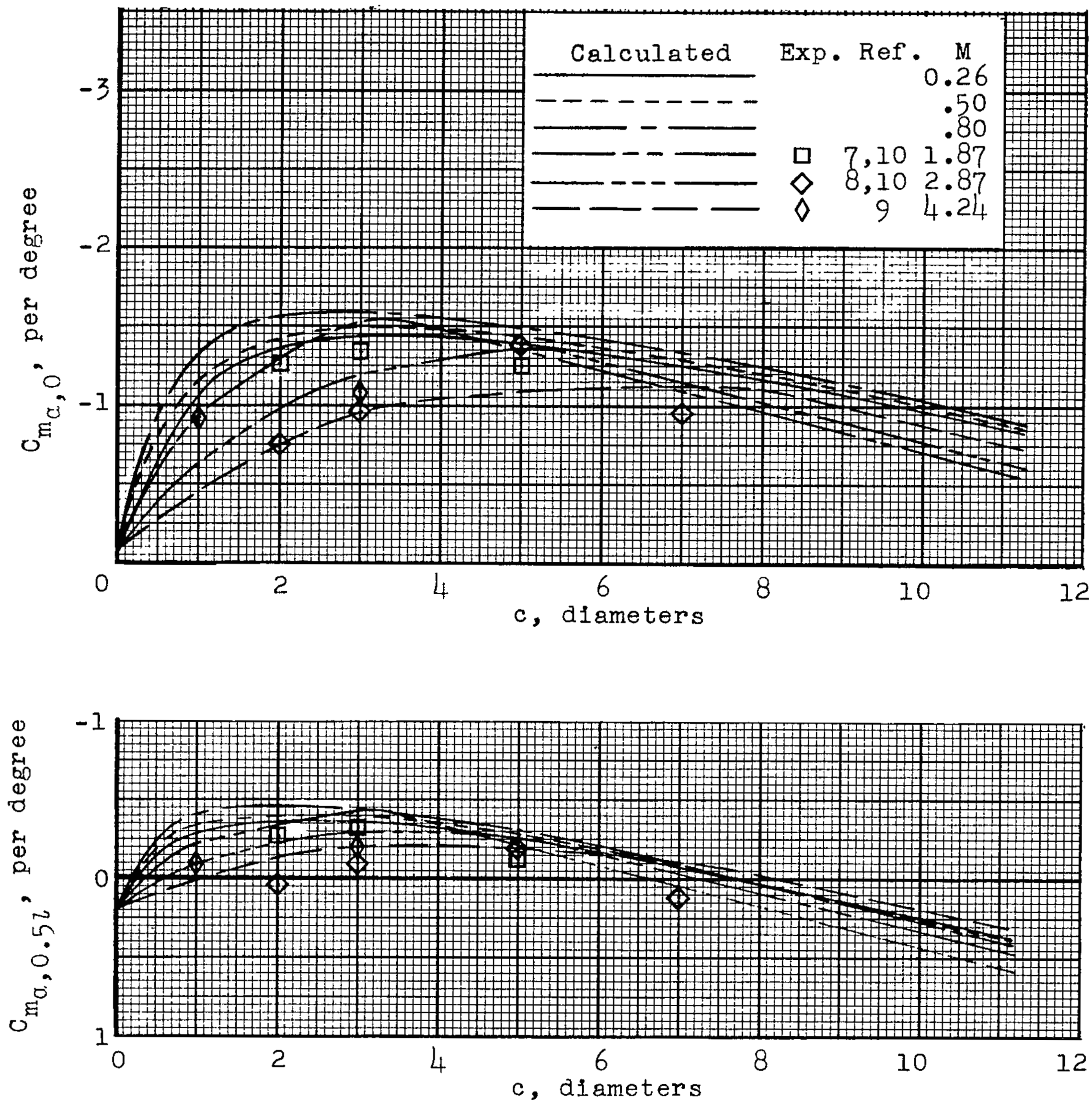
(a) d/b = 0.33.

Figure 3.- Variation of $C_{L_{\alpha}}$, $C_{m_{\alpha}}$, and x_{cp} with c for the rectangular fin.



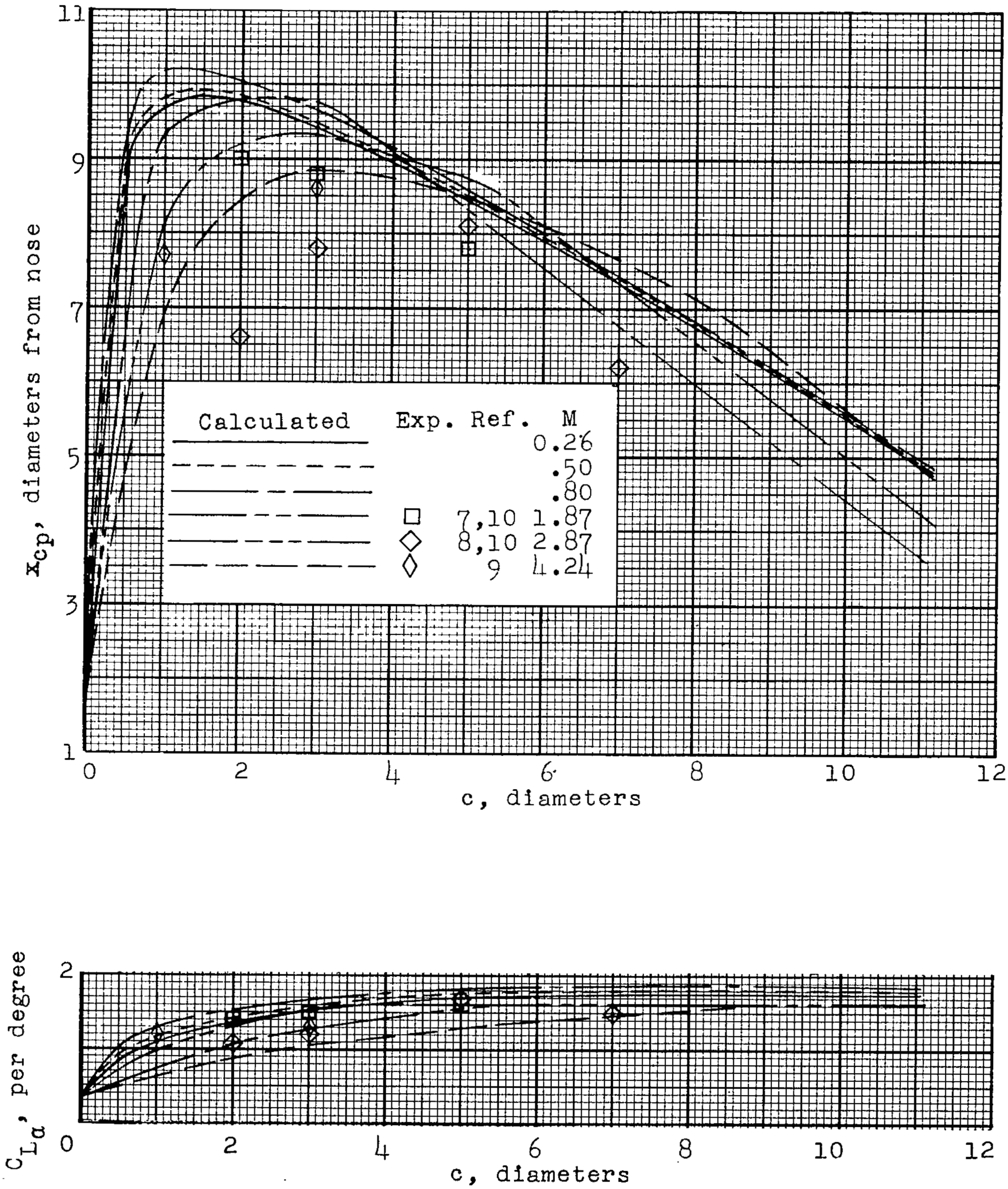
(a) Concluded.

Figure 3.- Continued.



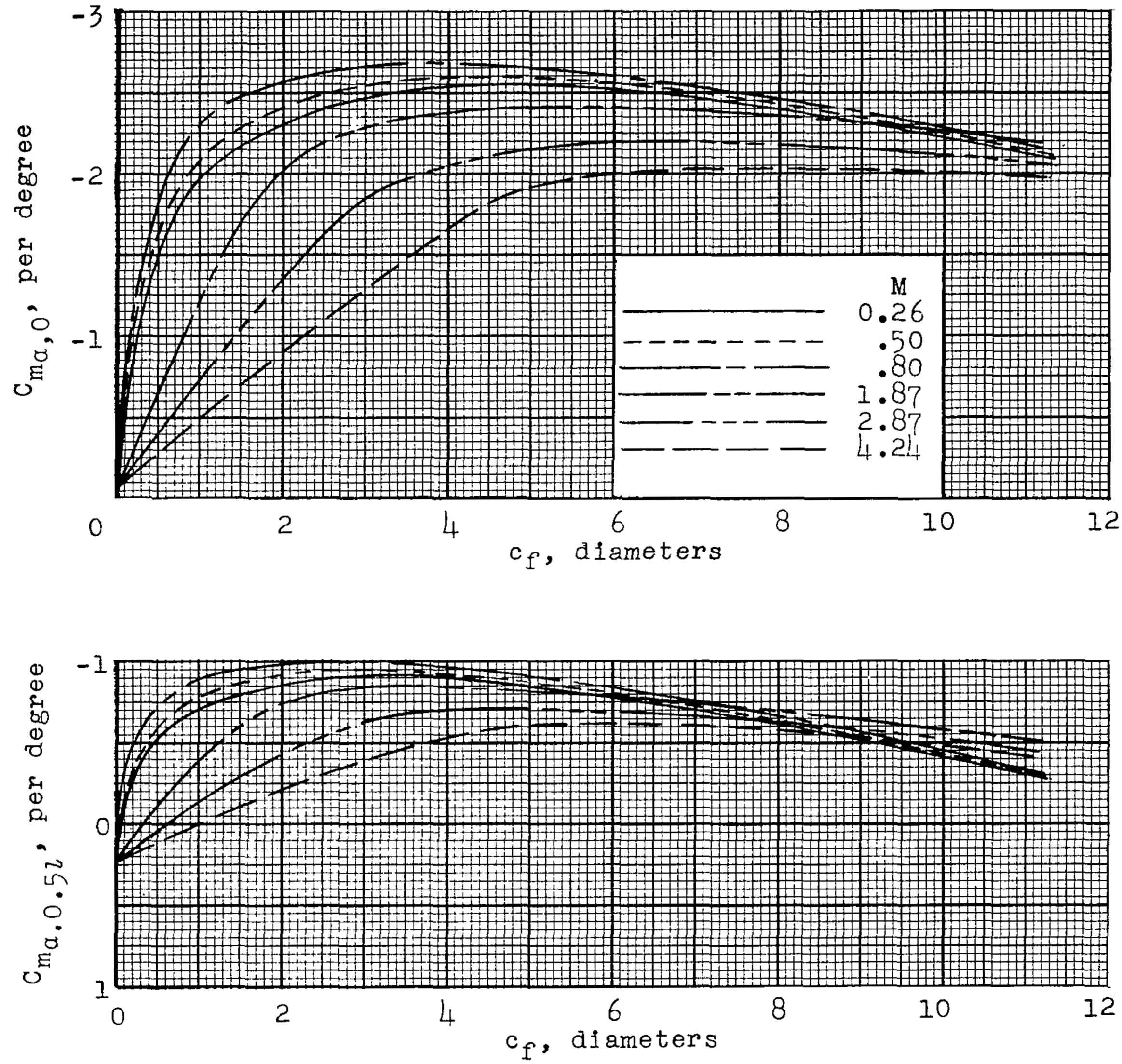
(b) d/b = 0.50.

Figure 3.- Continued.



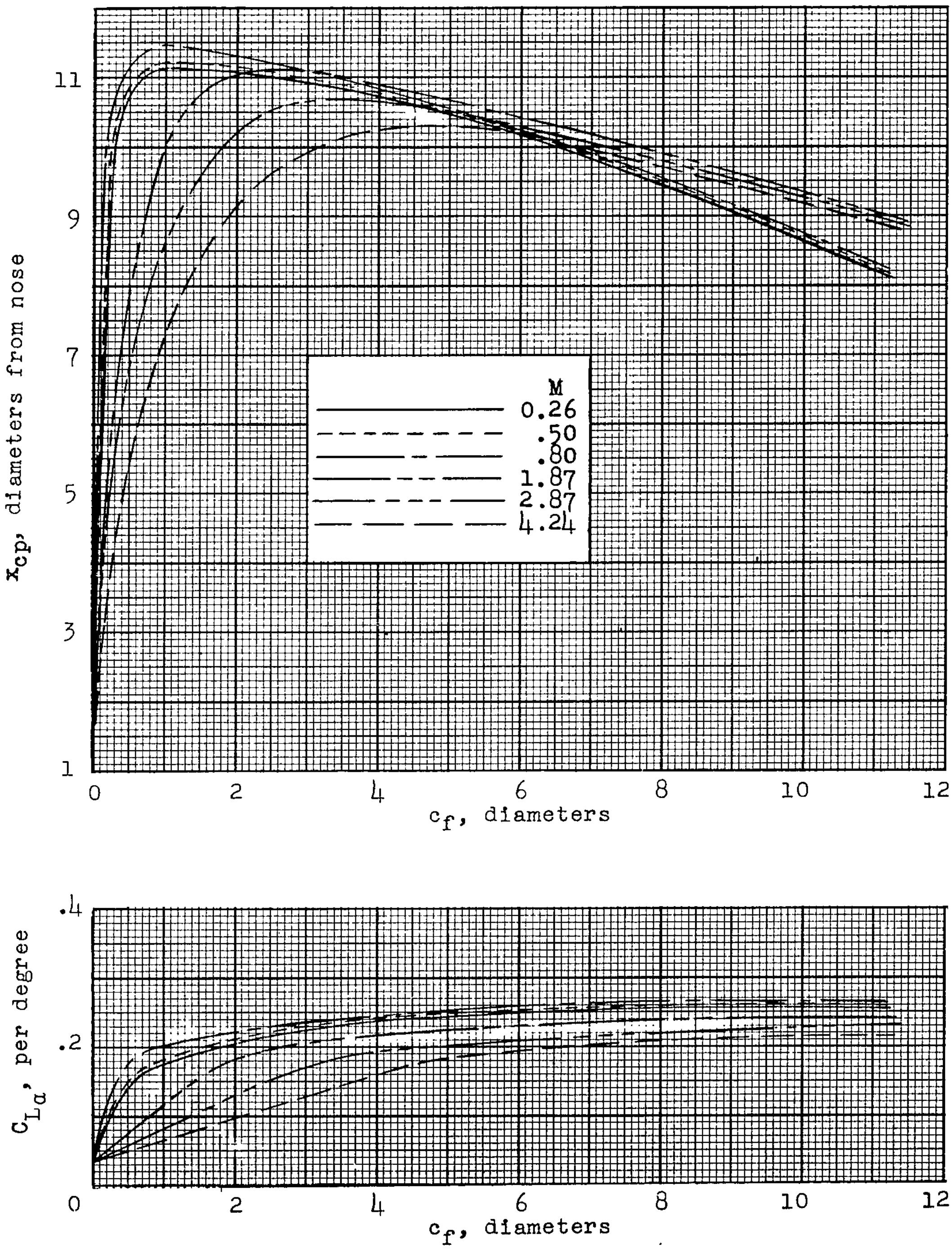
(b) Concluded.

Figure 3.- Concluded.



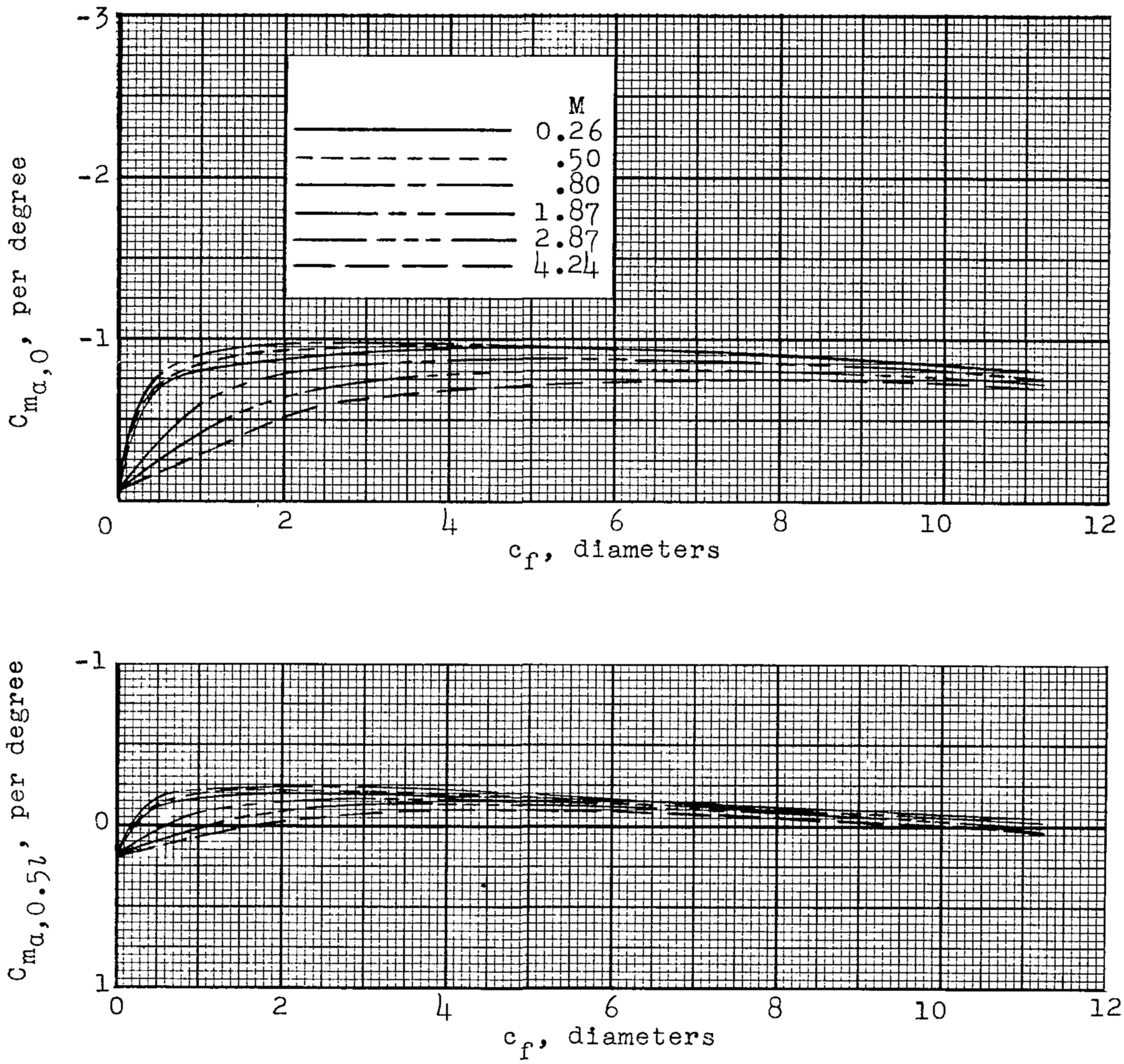
(a) d/b = 0.33.

Figure 4.- Variation of C_{L_α}, C_{m_α}, and x_{cp} with c_f for the triangular fin.



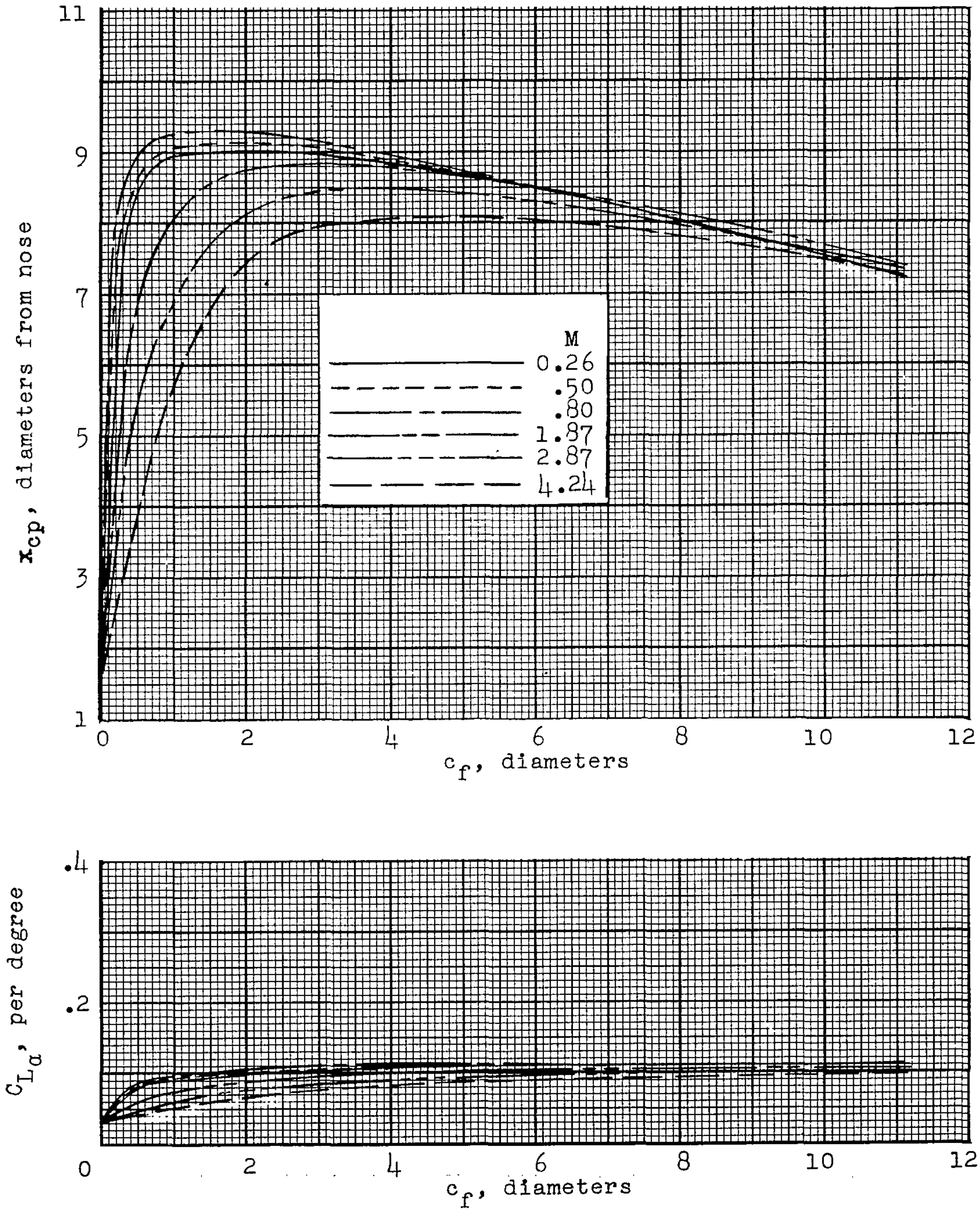
(a) Concluded.

Figure 4.- Continued.



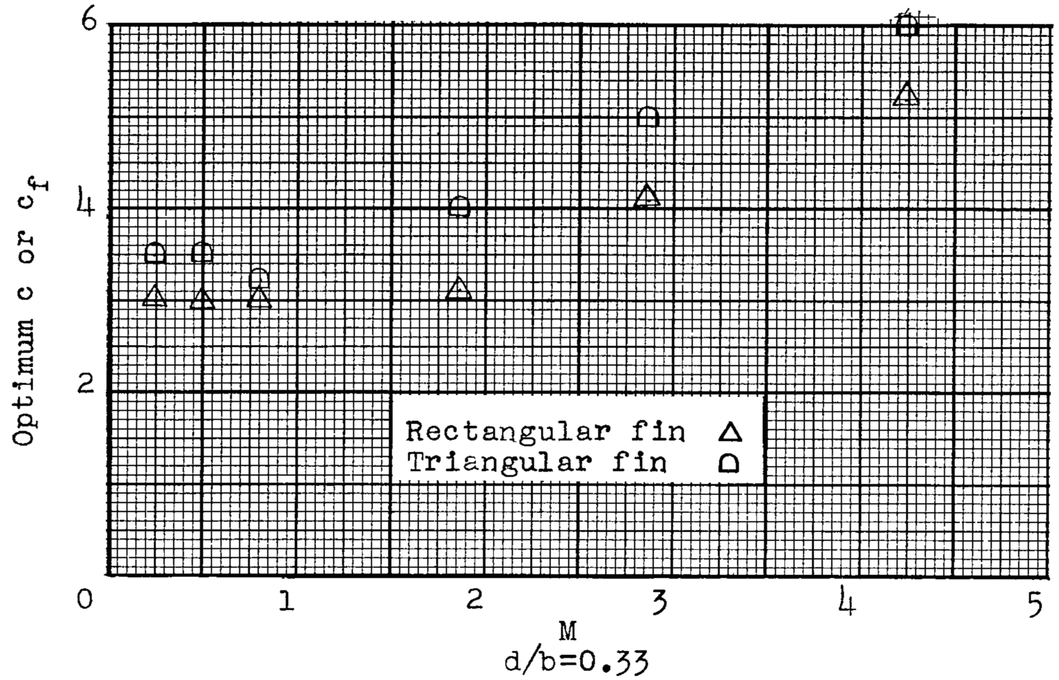
(b) d/b = 0.50.

Figure 4.- Continued.



(b) Concluded.

Figure 4.- Concluded.



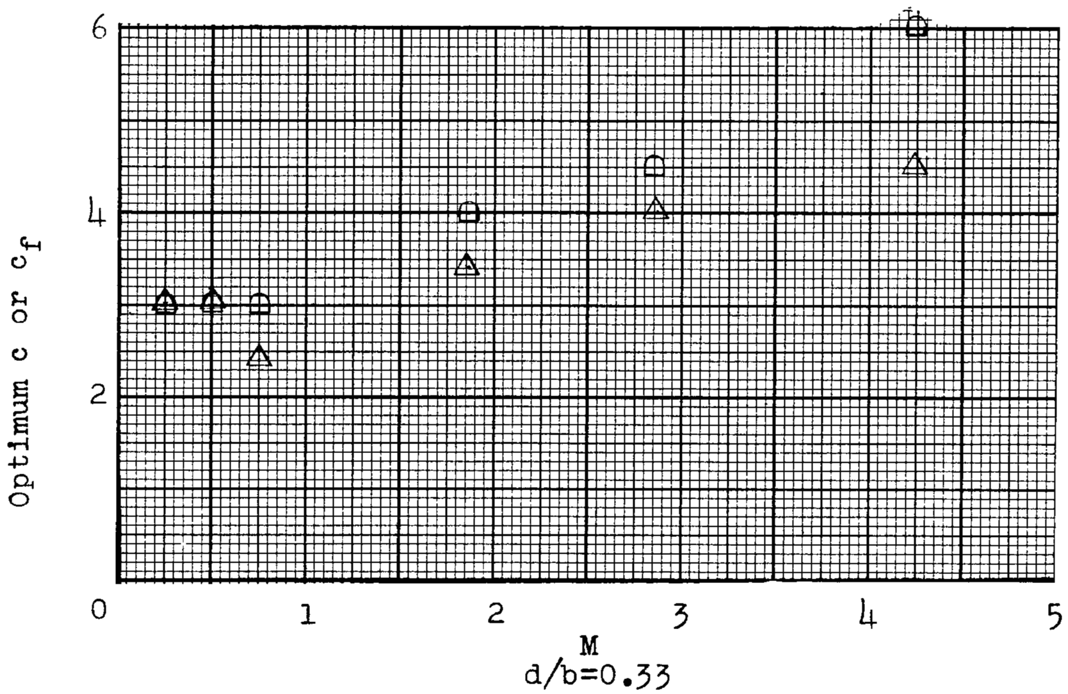


Figure 5.- Variation of optimum chord or root chord with Mach number.